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High-mountain hazards in the perspective of climate change effects: monitoring and assessment strategies

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Climate change particularly affects mountain regions. The increase in surface temperature in the last hundred years was observed to be higher than average in these areas, in some mountain ranges more than twice as high as the global average of 0.6°C. Rising temperatures have a strong effect on surface and subsurface ice which is reflected in the rapid shrinkage of mountain glaciers all over the world and the degradation of permafrost. Such often dramatic changes have serious implications with respect to hazards. (Kääb et al., 2005). Development and growth of glacial lakes leading to an increasing risk of devastating lake outburst floods is a prominent example found, for instance, in the Himalayas, the Andes and also in the Alps. UNESCO, for instance, recently issued a strong warning regarding lake outburst hazards in the Himalayas. In spite of inconsistencies in the recording of natural historical hazards, it seems that there has been an increase over the past decades in the frequency of lake outburst events in the Himalayas. In the Peruvian Andes, people have repeatedly suffered from major disasters from glacial lake outbursts in the last decades. Several thousand people died in associated floods and mass movements. New lakes are forming or existing ones growing, and considerable concern has thus risen that further lake outburst flood disasters might happen in the near future. In the Alps, less lives were lost in lake outburst events but the cost of damage has been significant. The most recent example stems from Täsch near Zermatt in the Swiss Alps where in 2001 a small lake outburst triggered a debris flow causing damages in the range of EUR 12 million.

Large slope instabilities in relation with changing hydro-thermal and hence mechanical conditions in steep mountain faces can be a further consequence and have already been observed, e.g. in case of the recent Kolka glacier disaster in the Caucasus that resulted from slope failure in connection with a glacier instability (Haeberli et al., 2004; Huggel et al., 2006). The Kolka ice-rock avalanche is highly remarkable in several aspects. In terms of the initial slope instability, it could be pathbreaking for future hazards to come in high-mountain regions. The steep and large mountain wall of the initial slope failure was covered by firn and ice masses which are known to be in a delicate state of stability. The underlying bedrock in relatively cold permafrost conditions was influenced by the thermal properties, and deep-seated thermal anomalies induced by the overlying ice and firn through processes such as latent heat production from percolating and refreezing meltwater (Haeberli et al., 2004). Warming atmospheric temperatures can cause disturbances in this complex and delicate system, which eventually can lead to slope failure. Similar conditions as in the Caucasus exist in many glacierized mountain regions of the world. In more populated areas such as the Alps, similarly large slope failures would represent a catastrophe of major dimensions. Interactions among different hazardous processes furthermore play an important role in controlling magnitude and frequency of hazards. Rock and ice avalanches impacting naturally and artificially dammed lakes generating impact waves and subsequently outburst floods are a typical example. Such interacting processes have to be assessed with anticipation in order to predict related consequences.

On the other hand, mountain regions continue to be economically developed. Areas of conflict between natural hazards and human activities are thus increasing. Related problems affect both developed and developing countries but the latter (e.g. in Central Asia, in the Himalayas or the Andes) often lack resources for adequate hazard mitigation measures. Cost-efficient methods are therefore needed to regularly monitor the rapid changes in high mountains and to identify the most vulnerable areas. This is also true for highly developed countries as Switzerland or its neighboring states in the Alps. Expensive protective structures have had to be built in the past to reduce the risk. Public funds increasingly get into

problems to keep pace with, and to ensure full protection of, the rapid developments in mountain areas. Vulnerability and risk studies integrating the consequences of climate change in high-mountain areas into robust models are required for achieving an optimal trade-off.

In consideration of the remoteness of high mountain regions, satellite remote sensing is an optimal tool for hazards monitoring and assessment. Recent developments in space technology have led to satellite sensors with particular focus on glaciers and include the possibility to generate digital elevation models (DEM) (Kargel et al., 2005). Methods have now been developed to detect the sources of glacial hazards, such as critical glacial lakes, potentially unstable steep glaciers and slopes with unconsolidated sediment prone to landslide and debris-flow processes (Huggel et al., 2004). Integration of remote sensing-derived information into process oriented and GIS models then allows the evaluation of hazards and their impacts on populated downstream areas. Flood-routing models, for instance, can be driven by remotely collected information on glacial lakes using remote sensing-derived DEMs to delineate areas potentially affected by lake outburst floods. First attempts have now also been undertaken to systematically model and assess potential process interactions (Huggel et al., 2004). High-resolution satellite images (e.g. QuickBird and IKONOS imagery) can furthermore be applied for disaster management and response in mountain terrains, e.g. to locate feasible access routes to the disaster area in difficult mountain topography (Huggel et al., 2006).

Satellite remote sensing techniques and readily applicable models for the assessment of hazard impacts as presented in this contribution are definitely required to cope with the decreasing degrees of freedom for actions due to accelerated rates of change of the natural high-mountain environment, ongoing economic development in mountain regions and limited financial resources for hazard mitigation.

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